Revision of Series in the Arc Spectrum of Mercury.

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[PLATES 4 AND 5.]

Introductory.

The generally accepted analysis of the arc spectrum of mercury into series is scattered throughout a number of papers by Paschen* and a paper by Wiedmann.† It shows the spectrum to contain a triplet and a singlet system of lines. Each system comprises the four main types of series—principal, diffuse, sharp and fundamental—and there are combinations and intercombinations among the systems. The scheme is partly collected by Dunz,‡ and again by McLennan,§ but in neither case is the complete arrangement given, so far as it is understood at present. Such a collection presents some difficulty, especially with regard to the diffuse triplet and singlet series and their combinations. Wiedmann gives the diffuse triplet series in such a form that the three components of a triplet, with satellites, contain respectively 3, 3 and 2 lines, instead of the customary 3, 2 and 1 lines. With this classification, he draws attention to a remarkable frequency difference relation between this series and the diffuse singlet series and its combinations. But, if this arrangement is adopted, the strong series of chief lines of the first components of the triplets, as given by Dunz, is left unaccounted for. It is possible, moreover, to retain Dunz's triplet, which has the ordinary form, and, by designating the then outstanding lines of Wiedmann's triplet as lines of combination series, to make the aforesaid frequency-difference relation a necessary result. This arrangement appears, on the whole, to be the better of the two. It has, however, the disadvantages that it involves the splitting up of what appear to be close associated groups of lines into members of different series, and, further, that it gives combination series, $2P-md''$, $2P-md'$—both consisting of very strong lines—without a trace of the corresponding series, $2P-md$, arising from the first chief line of the triplet.

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* 'Ann. d. Phys.,' vol. 29, p. 662 (1909); vol. 30, p. 750 (1909); vol. 35, p. 869 (1911); 'Jahrb. der Rad. und Elek.,' vol. 8, p. 178.

† 'Ann. d. Phys.,' vol. 38, p. 1041 (1912).

‡ 'Dissert. Tübingen,' 1911.

§ 'Roy. Soc. Proc.,' A, vol. 87, p. 256 (1912).

Suggested Rearrangement in Quadruplets.

In the present paper a new arrangement is attempted, which overcomes these difficulties. The triplets are associated with certain singlet series, and converted into quadruplets. It will be seen from the Tables which follow that, so far as numerical relations are concerned, the evidence for the recognition of quadruplets is complete. The characters of the lines, also, in the series which have been brought together, are quite in keeping with such association. The lines of the principal triplet series are said by Wiedmann to resemble in appearance those of the series with which they are here associated so closely as to be almost indistinguishable from them. He finds the distinction, however, in the fact that the latter lines are shaded towards the violet, while the triplets are shaded towards the red. In the case of the diffuse quadruplets, the added component, consisting of three lines, contains what is usually regarded as the diffuse singlet, and a pair of combination lines, which are equally strong and diffuse. The new component of the sharp quadruplet is described by Wiedmann as being particularly sharp. It appears, therefore, that there are strong reasons for supposing that we have in mercury a system of quadruplet series.

Quadruplet series have not so far been observed in any other spectrum. A number of quadruplets (groups of four lines having constant frequency differences) have been detected in the red spectrum of argon, but they have not been arranged in series, nor are the frequency differences related to one another in the same way as those of an ordinary series triplet or a mercury quadruplet. The present arrangement, therefore, introduces a new type of series. On this account, it has been thought advisable to employ Greek capital letters as symbols for the limits and terms, in order to distinguish them from those of the older established types.*

In the arrangement suggested, the spectrum consists of series of quadruplets and singlets. Five singlet series are recorded, including principal, diffuse, sharp, and two combination series. The three main series have been identified on the ground that they show the customary relations between the limits of such series. These relations can be satisfied also by a different selection, namely, the P, D and S series may be respectively Nos. IV, III and II, as numbered in the Tables. The former arrangement, however, seems more suited to the character of the lines. It will be observed that, with the exception of the series of terms mP, the whole of the singlet system can be derived from the quadruplets. If, therefore, the origin of the mP terms

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* The terms of triplet systems are usually denoted by small Latin letters (p, d, s, f), those of doublets by small Greek letters (π, δ, σ, ϕ), and those of singlets by Latin capitals (P, D, S, F).

could be found in the quadruplet system, the whole group of singlet series would become combinations, and the spectrum, so far as it is classified, would consist entirely of a quadruplet system and its derivatives. It has not been found possible so to explain the $m\mathrm{P}$ terms, however, so that, for the present, it seems best to regard the singlets as having a partially independent existence. In this connection, the following relations, while of no obvious significance at present, may be of some interest in view of possible future indications of a relation between the quadruplets and the $m\mathrm{P}$ terms:—
$2\mathrm{P}-4\mathrm{P} = (1\Sigma-2\Pi_3)+(1\Sigma-2\Pi_4)$; $3\mathrm{P}-5\mathrm{P} = 3\Sigma$; $2\mathrm{P}-5\Pi_1 = 1\Sigma-4\Pi_2$.

Structure of the Diffuse Series.

The diffuse quadruplet series calls for special attention, on account of its complicated structure. It will be seen from the Tables that, in the first member of the series, the four components contain, respectively, 3, 4, 3, 2 lines. It is customary, in complex series of this type, to select, from each component, one line, known as the chief line, while the others are classed as satellites. The chief line is usually the strongest of its group, and, in the first two components, is displaced in the direction of shorter wave-length by a satellite, which takes part in the constancy of frequency interval characterising diffuse doublet and triplet series. This, however, is by no means a universal rule. In selenium and manganese, for instance, there are decided anomalies. In the case of the mercury quadruplets also, no such simple separation into chief lines and satellites appears to be possible. It is probably better, therefore, to regard each component as being a complex group of chief lines, containing, respectively, 3, 4, 3, 2 lines, as already mentioned. This interpretation receives some support from the fact that, in the third and subsequent members of the series, fainter lines make their appearance in the second component of the quadruplet—one on either side of the main group. In the third quadruplet there is also an extra companion on the side of shorter wave-length—which may, indeed, be present, though unresolved, in the following members. These fainter lines, which are printed in italics or underlined in the Tables, might well be regarded as satellites. They are given here for the first time, having been detected and measured on an excellent plate taken by Mr. F. S. Phillips in the Spectroscopic Laboratory at the Imperial College of Science and Technology, by a method to be described later. The plate, with the analysis of the spectrum into series, is reproduced in Plate 4. In Plate 5 a portion of the spectrum is given on a larger scale, which brings out very clearly the second components of the higher members of the diffuse and sharp quadruplets. The second member of the diffuse quadruplet series is shown completely on the same plate, together with the interpretation of the lines on what has been referred to in the first paragraph as probably the better of the two existing views of the structure of the series. The second component of the third member also is there reproduced, with satellites which have no equivalent in the corresponding component of the second member.

The complex nature of the diffuse quadruplet series has its effect on the derived fundamental series. It will be seen that the first diffuse quadruplet has four "terms"—$m\Delta'''$, $m\Delta''$, $m\Delta'$ and $m\Delta$. There should, therefore, be a fundamental series of quadruplets, if the proposed arrangement is correct. This series has been found, and its "terms," $m\Phi$, take part also in a combination series with the limits of the subordinate quadruplet series.

[*Note added July* 28, 1921.—Since this paper was written, all but one of the series of lines, $1\Pi_2 - m\Delta_1$, described as "satellites," have been identified as the combinations $1\Pi_2 - m\Pi_2$. Thus, $1\Pi_2 - 5\Delta_1$ should be $1\Pi_2 - 5\Pi_2$, and so on for all higher members of the series. The line $1\Pi_2 - 4\Delta_1$, however, is not identical with $1\Pi_2 - 4\Pi_2$. The latter combination would be $\nu = 35533{\cdot}6$, or $\lambda = 2813{\cdot}42$, which differs by nearly 3 Å.U. from the measured line. There appears, therefore, in this case, to be an actual satellite.

Mr. Takamine, of Tokyo, has suggested to the author that the second series of "satellites," $1\Pi_2 - m\Delta_2$, may be the combinations $1\Pi_2 - m\Phi$. The combinations $1\Pi_2 - 3\Phi$ and $1\Pi_2 - 4\Phi$ are already included in the Tables with the quadruplet series $1\Pi_{1,\,2,\,3,\,4} - m\Phi$. The remaining $m\Phi$ terms are not known, but extrapolation by means of a Hicks formula gives the following results, which strongly support the suggestion of Mr. Takamine:—

m.	Extrapolated values of $m\Phi$.	Combination, $1\Pi_2 - m\Phi$.	Observed lines, classed as $1\Pi_2 - m\Delta_2$.
		ν.	ν.
5	3074	37064	37063·5
6	2256	37882	37884·2
7	1726	38412	38415·1]

Discussion of the New Arrangement.

The chief objection to the new arrangement of the mercury spectrum seems to be that it has no analogue in the spectra of the chemically-related elements zinc and cadmium. There is, however, so far as we know, no fundamental necessity for an element to follow the course of the earlier members of its group in the periodic table. In both its physical and chemical properties mercury shows wide divergences from zinc and cadmium, which exceed, in fact, those we might expect from the possible absence of an element between zinc and cadmium in the family group. There appears to be no reason why such divergences should not characterise the spectrum also. In some respects they are known to do so. For example, in the alkalis and alkaline earths, the limits of all the principal, sharp and diffuse series that occur (taking the first components of doublets and triplets) decrease in wave-number as we proceed along the family from the lighter to the heavier elements. Zinc and cadmium show the same tendency, but in mercury, in all cases except that of the diffuse and sharp triplets (here, diffuse and sharp quadruplets), the limits are higher than the corresponding ones of cadmium. A similar decrease characterises also the ionisation potentials of the alkalis, alkaline earths, and zinc and cadmium—but fails again when we come to mercury. It appears, therefore, that novel features in the structure of the mercury spectrum are not to be altogether unexpected. The reality of the quadruplets is enhanced in probability when we consider the conditions that have to be fulfilled in order to construct them from a triplet system. There must be a singlet series having the same limit ($1s$) as the principal triplets; two singlet series, having identical limits, and the same terms (ms and md) as the sharp and diffuse triplets, respectively; and possibly series with terms md', md''. The lines of the first of these series (having the limit $1s$) must lie on the opposite side of the principal triplets to that occupied by the lines of the other two required singlet series with relation to the respective subordinate triplets. Also, the difference between the limit of the first series and the wave-number of its first member must be the common limit of the other two series. In our ignorance of the principles underlying the association of triplet and singlet series, the chance that these conditions will all be fulfilled in the same spectrum appears to be very small. They are, in fact, not even approximately satisfied in any known spectrum other than that of mercury, except the spectrum of cadmium. Here they partially hold, but not at all completely, and the distances between the triplets and such of the required singlet series as exist are so great, compared with the triplet separations, as to preclude any possibility of their association. This unique property of the mercury spectrum, against what appear to be heavy odds, affords strong evidence for the recognition of quadruplets. The probability is increased still further when we find that the separations of the components of the quadruplets are in the approximate ratio we should expect from our knowledge of triplets, and, moreover, that a fundamental series of quadruplets exists, as well as a quadruplet combination series. There is, in fact, precisely the same evidence here for the existence of quadruplet series as there is for recognising, in some other spectrum, the existence of triplets rather than doublets and singlets separately.

Observation of New Series Lines.

In the Tables that follow, all the measures are expressed on the International Scale. In the case of Paschen's infra-red lines, the values have been corrected in the manner pointed out by him* on account of errors of calculation in the original values. Existing measures have been utilised as far as possible, but many of the lines included are now given for the first time. These have been measured from the plate already referred to, which was taken by means of a quartz Littrow spectrograph, giving a dispersion of 7·9 Å.U. per millimetre at λ2400 and 12·9 Å.U. per millimetre at λ2800. The spectrum was produced by means of the apparatus illustrated in fig. 1. The mercury was contained in a long U-tube, having the left-hand limb prolonged into a wide quartz tube, into which a small cylinder of iron, pierced with a central hole, was fixed just above the level of the mercury. The quartz tube was connected to a pump, so that it could be exhausted. The mercury and iron cylinder were connected to the source of current, and the arc was struck by raising the right-hand limb of the U-tube until contact was established between the mercury in the left-hand limb and the iron. The upper part of the quartz tube was then exhausted, and the flame of the arc was thereby sucked through the hole in the iron into the space above. The spectrum shown in the Plates was due to this flame. It will be observed that it consists almost entirely of series lines, which appear by this method to be produced free from the large number of unclassified lines which are present in the ordinary arc. On account of the smallness of the dispersion, and the nebulous character of many of the lines, the new measures are considered to have a maximum error of 0·03 Å.U. The sharp lines will probably have an error of less than this. A remarkable feature of the plate is that the line 2534·77 appears distinctly stronger than the resonance potential line 2536·52. Cardaun† gives the intensities of these lines as (4) and (10) respectively. The intensities

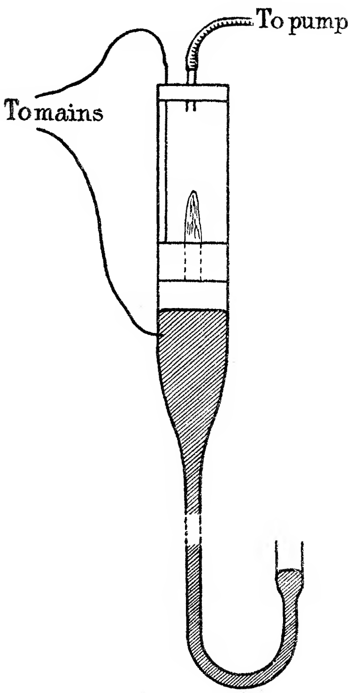

FIG. 1.

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* 'Ann. d. Phys.,' vol. 36, p. 197 (1911).

† 'Zeit. für Wiss. Phot.,' vol. 14, p. 89 (1915).

given in the Tables have, in a few cases, been adjusted, in order to preserve the true succession of intensity throughout a series. Different observers adopt different standards, and as Stiles* remarks, the intensities of mercury lines vary greatly with the conditions of production of the spectrum. No alterations have been made, however, without verifying that the numbers given represent relatively the actual observations.

In the Tables, the wave-lengths and wave-numbers are denoted respectively by λ and ν, and the "terms" by $m\Pi$, $m\Sigma$, etc. The column headed $\Delta\nu$ shows the wave-number separations of the components of quadruplets. In the diffuse series, the separations of the constituent lines of each component are also given under this heading. The value of 1Σ has been obtained by correcting Wiedmann's figure (*loc. cit.*) to the International Scale. The other limits have then been calculated from observed lines in the usual way.

The newly-measured lines are indicated by footnotes.

The letters sometimes included with the intensities have the following meanings:—*n* = nebulous, *r* = nebulous on red side, *v* = nebulous on violet side, R = easily reversed.

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* 'Astrophys. Journ.,' vol. 30, p. 48 (1909).

Principal Quadruplets.

	Current Designation.	
$1\Sigma - m\Pi_1$	$2 \cdot 5s - mP$	—Combination.
$1\Sigma - m\Pi_2$	$2 \cdot 5s - mp_1$	—Principal Triplets.
$1\Sigma - m\Pi_3$	$2 \cdot 5s - mp_2$	
$1\Sigma - m\Pi_4$	$2 \cdot 5s - mp_3$	

$1\Sigma = 21830 \cdot 8$

m.	λ and intensity.	ν.	Δν.	*m*Π.
1	−12070·23	−8282·7	10024·8	30113·5
	−5460·74 (10)	−18307·5	4630·6	40138·3
	−4358·34 (10)	−22938·1	1767·3	44768·9
	−4046·56 (10)	−24705·4		46536·2
2*	?	?	—	—
	11287·15 (10)	8857·3	1545·6	12973·5
	13673·09 (6)	7311·7	145·5	14519·1
	13950·76 (2)	7166·2		14664·6
3	6072·63 (5)	16462·9	1989·9	5367·6
	6907·53 (10)	14473·0	356·6	7357·8
	7082·01 (4)	14116·4	20·2	7714·6
	7092·20 (1*r*)	14096·2		7734·4
4	5675·86 (5)	17614·5	388·4	4216·3
	5803·55 (4*r*)†	17226·1	164·0	4604·7
	5859·32 (4*r*)‡	17062·1	37·1	4768·7
	5872·12 (2)	17025·0		4805·8

Principal Quadruplets—(*continued*).

m.	λ and intensity.	ν.	Δν.	$m\Pi$.
5	5316·69 (3*v*)	18803·6	131·2	3027·2
	5354·05 (4*r*)	18672·4	106·3	3158·4
	5384·70 (3*r*)§	18566·1	14·9	3264·7
	5389·01 (1)	18551·2		3279·6
6	5102·42 (2*v*)	19593·1	69·7	2237·7
	5120·65 (3*r*)	19523·4	66·3	2307·4
	5138·09 (1)	19457·1	7·6	2373·7
	5140·10 (1)	19449·5		2381·3
7	4970·13 (1*v*)	20114·7	43·2	1716·1
	4980·82 (3*r*)	20071·5	43·0	1759·3
	4991·5 (2)	20028·5		1802·3
	—	—		—
8	4883·1 (1)	20474·5	31·4	1356·3
	4890·27 (2*r*)	20443·1	27·7	1387·7
	4896·9 (1)	20415·4		1415·4
	—	—		—
9	4822·3 (1)	20731·3	20·6	1099·5
	4827·1 (2)	20710·7	21·9	1120·1
	4832·2 (1)	20688·8		1142·0
	—	—		—
	2nd compo	nent only.		
10	4782·1 (1)	20905·6		925·2
11	4748·1 (1)	21055·2		775·6
12	4722·8 (1)	21168·0		662·8
13	4701·8 (1)	21262·5		568·3
14	4685·3 (1)	21337·3		493·5
15	4672·7 (1)	21394·8		436·0
16	4662·4 (1)	21442·3		388·5
17	4653·4 (1)	21483·8		347·0

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* Paschen ('Ann. d. Phys.,' vol. 35) hesitates between this triplet and (12390·7), 13950·76, (?) — the latter being indicated by a Hicks formula. The line $1P-2\Pi_3$, however, afterwards discovered by Woolf, indicates that the triplet given in the Table is the true one.

† This line occurs also as $2P-5\Pi_1$. It is very diffuse, and is considered by Paschen to arise from both sources.

‡ Has satellites 5860·10 and 5868·08.

§ Has satellite 5385·79.

Sharp Quadruplets.

Current Designation.

$1\Pi_1 - m\Sigma$ .... $2P - ms$ — Combination.

$1\Pi_2 - m\Sigma$ .... $2p_1 - ms$ }

$1\Pi_3 - m\Sigma$ .... $2p_2 - ms$ } — Sharp Triplets.

$1\Pi_4 - m\Sigma$ .... $2p_3 - ms$ }

$1\Pi_1 = 30113·5$; $1\Pi_2 = 40138·3$; $1\Pi_3 = 44768·9$; $1\Pi_4 = 46536·2$.

m.	λ and intensity.	ν.	Δν.	*m*Σ.
1	12070·23	8282·7	10024·8	21830·8
	5460·74 (10)	18307·5	4630·6	21830·8
	4358·34 (10)	22938·1	1767·3	21830·8
	4046·56 (10)	24705·4		21830·8
2	5025·56 (3)	19892·7	10025·6	10220·8
	3341·48 (6)	29918·3	4630·8	10220·0
	2893·60 (5)	34549·1	1767·3	10219·8
	2752·78 (4)	36316·4		10219·8
3	4140·03 (1)	24147·9	10025·5	5965·6
	2925·41 (4)	34173·4	4630·7	5964·9
	2576·29 (3)	38804·1	1767·4	5964·8
	2464·06 (2)	40571·5		5964·7
4	3815·84 (1)	26199·3	10026·0	3914·2
	2759·70 (3)	36225·3	4630·8	3913·0
	2446·90 (2)	40856·1	1767·4	3912·8
	2345·43 (1)	42623·5		3912·7
5	—	—		—
	2674·99 (2)	37372·5	4632·1	2765·8
	2379·99 (1)	42004·6		2764·3
	—	—		—
6	—	—		—
	2625·24 (2)	38080·7	4630·8	2057·6
	2340·60 (1)	42711·5		2057·4
	—	—		—
	2nd component only.			
7	2593·41 (1)	38548·0		1590·3
8	2571·75 (1)*	38872·7		1265·6
9	2556·30 (1)*	39107·6		1030·7
10	2544·87 (1)*	39283·2		855·1
11	—†	—		—
12	2529·53 (1)*	39521·5		616·8
13	2524·11 (1)*	39606·3		532·0
14	2519·79 (0)*	39674·2		464·1
15	2516·32 (0)*	39728·9		409·4

* Newly-measured lines.

† Probably obscured by 2536·52.

Diffuse Quadruplets.

Current Designation.

$1\Pi_1 - m\Delta'''$ .... $2P - mD$ — Diffuse Singlets.
$1\Pi_1 - m\Delta''$ .... $2P - md''$ } — Combination.
$1\Pi_1 - m\Delta'$ .... $2P - md'$

$1\Pi_2 - m\Delta_1$ .... —
$1\Pi_2 - m\Delta'''$ .... $2p_1 - mD$ — Combination.
$1\Pi_2 - m\Delta''$ .... $2p_1 - md''$ }
$1\Pi_2 - m\Delta'$ .... $2p_1 - md'$ } — Diffuse Triplets.*
$1\Pi_2 - m\Delta$ .... $2p_1 - md$ }
$1\Pi_2 - m\Delta_2$ .... —

$1\Pi_3 - m\Delta'''$ .... $2p_2 - mD$ — Combination.
$1\Pi_3 - m\Delta''$ .... $2p_2 - md''$ } — Diffuse Triplets.*
$1\Pi_3 - m\Delta'$ .... $2p_2 - md'$

$1\Pi_4 - m\Delta'''$ .... $2p_3 - mD$ — Combination.
$1\Pi_4 - m\Delta''$ .... $2p_3 - md''$ — Diffuse Triplets.*

$1\Pi_1 = 30113\cdot5$; $1\Pi_2 = 40138\cdot3$; $1\Pi_3 = 44768\cdot9$; $1\Pi_4 = 46536\cdot2$.

m.	λ and intensity.	ν.	Δν.	mΔ, etc.
2	5790·66 (10r)	17264·5	2·9	12849·0
	5789·69 (2)	17267·4	60·1	12846·1
	5769·60 (10r)	17327·5		12786·0
			10025·7	
	3663·28 (5)	27290·2	3·0	12848·1
	3662·88 (4r)	27293·2	60·1	12845·1
	3654·83 (6)	27353·3	35·1	12785·0
	3650·15 (10)	27388·4		12749·9
			4630·8	
	3131·84 (7)	31921·0	2·9	12847·9
	3131·55 (7)	31923·9	60·1	12845·0
	3125·66 (8)	31984·0		12784·9
			1767·5	
	2967·52 (1)	33688·5	2·7	12847·7
	2967·28 (5)	33691·2		12845·0
3	4347·50 (6n)	22995·3	20·4	7118·2
	4343·64 (2)	23015·7	23·4	7097·8
	4339·23 (4)	23039·1		7074·4
			10025·9	
	3027·48 (2)	33021·2	20·4	7117·1
	3025·62 (2)	33041·6	23·4	7096·7
	3023·47 (4)	33065·0	21·6	7073·3
	3021·50 (5)	33086·6		7051·7
			4630·8	
	2655·13 (4)	37652·0	20·5	7116·9
	2653·68 (4)	37672·5	23·3	7096·4
	2652·04 (5)	37695·8		7073·1
			1767·3	
	—	—†		—
	2534·77 (4)	39439·8		7096·4
4	3906·40 (4n)	25591·8	18·1	4521·7
	3903·64 (2)	25609·9	11·4	4503·6
	3901·90 (2n)	25621·3		4492·2
			10025·1	

Diffuse Quadruplets—(*contd.*)

m.	λ and intensity.	ν.	Δν.	*m*Δ.
4	*2810·51 (0)‡*	*35570·5*		*4567·8*
	2806·84 (1)	35616·9	*46·4*	4521·4
	2805·42 (1)	35634·9	18·0	4503·4
	2804·46 (2)	35647·1	12·2	4491·2
	2803·48 (4)§	35659·6	12·5	4478·7
	2801·22 (0)‡	*35688·4*	*28·8*	*4449·9*
			4631·7	
	2483·83 (2)	40248·6		4520·3
	2482·72 (3)	40266·6	18·0	4502·3
	2482·01 (4)	40278·1	11·5	4490·8
			1765·2	
	2379·46	42013·8		4522·4
	2378·34 (3)	42033·8	20·0	4502·4
5	3704·22 (1)	26988·6		3124·9
	3702·36 (1)	27002·3	13·7	3111·2
	3701·44 (1)	27008·8	6·5	3104·7
			10025·0	
	2703·50 (0)‡	*36978·3*		*3160·0*
	2700·92 (1)	37013·6	*35·3*	3124·7
	—	—	} 19·5	—
	2699·50 (1*n*)	37033·1		3105·2
	2698·85 (3*n*)	37042·0	8·9	3096·3
	2697·29 (1)	*37063·5*	*21·5*	*3074·8*
			4631·8	
	2400·52 (0)	41645·4		3123·5
	2399·74 (2)	41658·9	13·5	3110·0
	2399·38 (3)	41665·2	6·3	3103·7
			1767·0	
	—	—		—
	2302·09 (2*n*)	43425·9		3110·3
6	3592·97 (1)	27824·4		2289·1
	3591·48 (1)	27835·9	11·5	2277·6
	3590·95 (1)	27840·0	4·1	2273·5
			10027·4	
	2642·48 (0)‡	*37832·2*		*2306·1*
	2641·11 (1)‡	37851·8	*19·6*	2286·5
	—	—		—
	2639·93 (3*n*)‖	37868·7		2269·6
	2638·85 (1)‡	*37884·2*		*2254·1*
			4627·1	
	—	—		—
	—	—		—
	2358·48 (1*n*)	42495·8		2273·1
			1761·0	
	—	—		—
	2258·87 (1)	44256·8		2279·4
7	3524·27 (2)	28366·7		1746·8
	—	—		—
	3523·00 (1)	28377·2		1736·3
			10026·9	
	2604·73 (0)‡	*38380·5*		*1757·8*
	2603·84 (1)‡	38393·6	*13·1*	1744·7
	—	—		—
	2603·15 (2*n*)	38403·8		1734·5
	2602·38 (0)‡	*38415·1*	*11·3*	*1723·2*
			4625·7	
	—	—		—
	—	—		—
	2323·30 (1*n*)	43029·5		1739·4
	—	—		—
	—	—		—

First two components only.

Diffuse Quadruplets—(*contd.*)

m.	λ and intensity.	ν.	$\Delta\nu$.	$m\Delta$, etc.
8	3478·98 (1)	28736·4		1377·1
	—	—		—
	3477·85 (1)	28745·5		1368·0
	2579·58 (0)‡	*38754·6*	*10·2*	*1383·7*
	2578·91 (0)‡	38764·8		1373·5
	—	—		—
	2578·44 (1*n*)‡	38771·9		1366·4
9	3447·22 (1)	29001·0		1112·5
	—	—		—
	—	—		—
	2562·02 (0)‡	*39020·3*		*1118·0*
	—	—		—
	—	—		—
	2561·18 (1*n*)‡	39033·1		1105·2
	$1\Pi_2 - m\Delta$ and satellite only.			
10	*2549·24 (0)*‡	*39215·8*		*922·5*
	2548·55 (1*n*)‡	39226·6		911·7
11	2539·00 (1*n*)‡	39374·1		764·2
12	2531·69 (1*n*)‡	39487·8		650·5
13	2525·84 (1*n*)‡	39579·2		559·1
14	2521·23 (1*n*)‡	39651·5		486·8
15	2517·45 (1*n*)‡	39711·1		427·2
16	2514·26 (1*n*)‡	39761·4		376·9
17	2511·64 (1*n*)‡	39802·9		335·4
18	2509·47 (0*n*)‡	39837·3		301·0
19	2507·47 (0*n*)‡	39869·1		269·2
20	2505·87 (0*n*)‡	39894·5		243·8

---

* Wiedmann's diffuse triplet series, referred to in the paper, is, in the present notation—

$1\Pi_2 - m\Delta'''$	$1\Pi_3 - m\Delta'''$	$1\Pi_4 - m\Delta'''$
$1\Pi_2 - m\Delta''$	$1\Pi_3 - m\Delta''$	$1\Pi_4 - m\Delta''$
$1\Pi_2 - m\Delta'$	$1\Pi_3 - m\Delta'$	

As stated, this leaves the strong series, $1\Pi_2 - m\Delta$, unaccounted for.

† Frequency difference relations require $\nu = 39419·3$, *i.e.*, $\lambda = 2536·09$. This line would be weak, and is probably obscured by the strong line 2536·52.

‡ Newly-measured lines. See note in paper, added July 28, 1921.

§ This line has another newly-measured satellite, 2802·76 (1).

|| This line, and the corresponding lines of succeeding members of the series, represent the unresolved pairs, $1\Pi_2 - m\Delta'$, $1\Pi_2 - m\Delta$.

Fundamental Quadruplets.

	Current Designation.	
$2\Delta - m\Phi$	$3d - mf$	Fundamental Triplets.
$2\Delta' - m\Phi$	$3d' - mf$	
$2\Delta'' - m\Phi$	—	
$2\Delta''' - m\Phi$	$3d'' - mf$	Fundamental Triplets.

$2\Delta = 12749·9$; $2\Delta' = 12785·3$; $2\Delta'' = 12845·3$; $2\Delta''' = 12848·1$.

m.	λ and intensity.	ν.	Δν.	*m*Φ.
3	17193 (1) 17108·51 (1) 16938·86 (1) 16918·32 (2)	5814·8 5843·5 5902·0 5909·2	28·7 58·5 7·2	6935·1 6941·8 6943·3 6938·9
4	12020·20 (1) — 11886·64 (1)*	8317·2 — 8410·6		4432·7 — 4434·7 4437·5

* Stated by Paschen to be a double line, with wave-length separation of 10 Å.U.

Quadruplet Combination Series.

	Current Designation.	
$1\Pi_1 - m\Phi$	—	
$1\Pi_2 - m\Phi$	$2p_1 - mf$	– Combination.
$1\Pi_3 - m\Phi$	$2p_2 - mf$	
$1\Pi_4 - m\Phi$	$2p_3 - mf$	

$1\Pi_1 = 30113·5$; $1\Pi_2 = 40138·3$; $1\Pi_3 = 44768·9$; $1\Pi_4 = 46536·2$.

m.	λ and intensity.	ν.	Δν.	ν (calc.).†	Δν (calc.).
3	4313·3 (1*v*) 3011·05 (1*n*) 2642·60 (6*v*)* 2524·71 (1*r*)	23177·7 33201·4 37830·5 39596·9	10023·7 4629·1 1766·4	23173·7 33198·5 37829·1 39596·4	10024·8 4630·6 1767·3
4	3893·89 (1*n*) 2799·83 (2) 2478·66 (1) 2374·02 (2*n*)	25674·2 35706·1 40332·6 42110·2	10031·9 4626·5 1777·6	25679·1 35703·9 40334·5 42101·8	10024·8 4630·6 1767·3

* Intensity given is by Kayser and Runge. Stiles gives it as (1). Intensity is probably affected by neighbourhood of $1\Pi_2 - 6\Delta_1$.

† The discrepancies between observed and calculated wave-numbers of some of these lines may partly be attributed to uncertainty in the values of *m*Φ. The fundamental series is well in the infra-red, and, as shown above, the values of *m*Φ from different components show rather large variations. The mean values of *m*Φ have been adopted in this column

Singlet System.

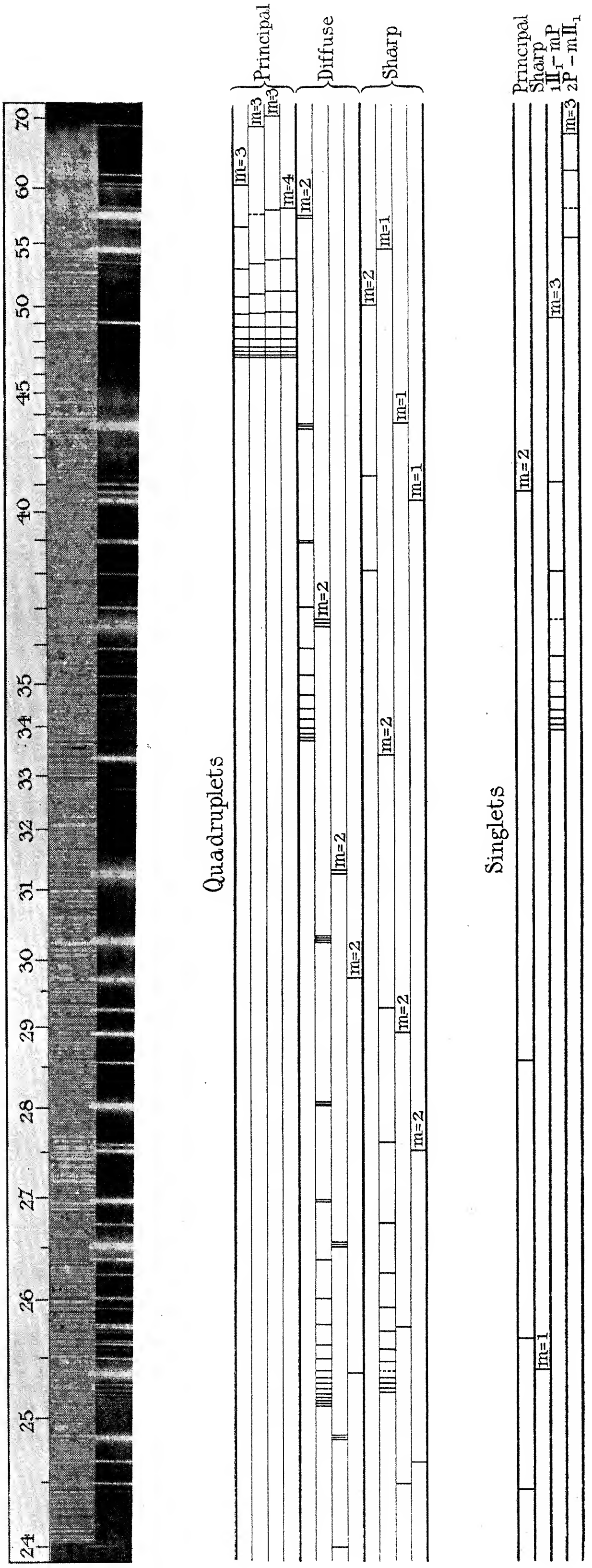
	m.	λ and intensity.	ν.	mP.	Current Designation.
I. Principal Singlets— $1\Pi_3 - m$P ...... $1\Pi_3 = 44768 \cdot 9$	1	$-2536 \cdot 52$ (10R)	$-39412 \cdot 6$	84181 ·5	$2p_2 - m$S — Combination.
	2	4077 ·83 (7r)	24515 ·9	20253 ·0	
	3	2856 ·94 (1)	34992 ·4	9776 ·5	
	4	2563 ·90 (1)	38991 ·7	5777 ·2	
	5	2441 ·03 (1)*	40954 ·4	3814 ·5	
II. Diffuse Singlets— $1\text{P} - m\Pi_1$ ...... 1P = 84181 ·5.				$m\Pi_1$.	
	1	1849 ·57	54065 ·7	30115 ·8	1 ·5 S — mP — Principal Singlets (1).
	2	1402 ·72 (?)†	71290 ·6	12890 ·9 (?)	
III. Sharp Singlets— $1\text{P} - m\Pi_3$ ...... 1P = 84181 ·5.				$m\Pi_3$.	
	1	2536 ·52 (10R)	39412 ·6	44768 ·9	1 ·5 S — mp_2 — Combination.
	2	1435 ·63	69655 ·8	14525 ·7	
IV. Combination Series— $1\Pi_1 - m$P ...... $1\Pi_1 = 30113 \cdot 5$.				ν (calc.)	
	1	$-1849 \cdot 57$	$-54065 \cdot 7$	$-54068 \cdot 0$	2P — mS — Sharp Singlets.
	2	10139 ·67	9859 ·7	9860 ·5	
	3	4916 ·04 (4r)	20335 ·9	20337 ·0	
	4	4108 ·08 (2n)	24335 ·4	24336 ·3	
	5	3801 ·67 (2)	26296 ·8	26299 ·0	
V. Combination Series— $2\text{P} - m\Pi_1$ ...... 2P = 20253 ·0.	1	$-10139 \cdot 67$	$-9859 \cdot 7$	$-9860 \cdot 5$	2 ·5 S — mP — Principal Singlets (2).
	2	?	?	?	
	3	6716 ·45 (5)	14884 ·8	14886 ·1	
	4	6234 ·35 (8)	16035 ·8	16036 ·7	
	5	5803 ·55 (4r)‡	17226 ·1	17225 ·8	
	6	5549 ·28 (3r)	18015 ·4	18015 ·3	
	7	5393 ·50 (2)	18535 ·8	18536 ·9	
	8	5290 ·1 (2)	18897 ·9	18896 ·7	
	9	5218 ·9 (2)	19155 ·7	19153 ·5	
	10	5165 ·8 (1)	19352 ·2	—	
	11	5128 ·9 (1)	19492 ·0	—	

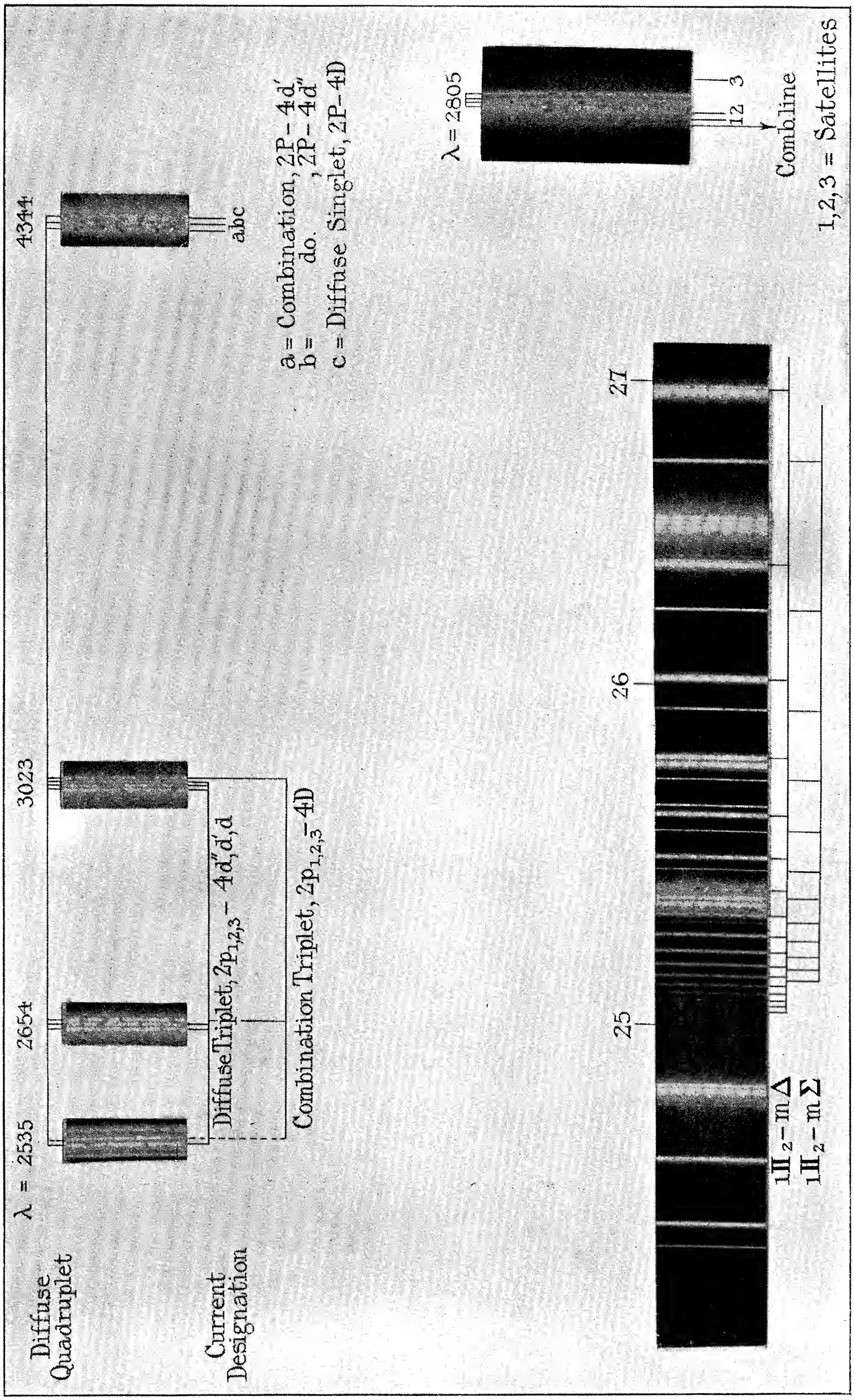
---

* Newly-measured line.

† Paschen so classifies this line by assuming $\lambda 13570 \cdot 68$ to be the line $2\text{P} - 2\Pi_1$. He questions the truth of this, however, and the value of $2\Pi_1$ which it gives leads to a line for $1\Sigma - 2\Pi_1$ which has not been observed, and which is unlikely in view of its closeness to $\lambda 11287 \cdot 15$ ($1\Sigma - 2\Pi_2$). It is probable, therefore, that $\lambda 1402 \cdot 72$ and $\lambda 13570 \cdot 68$ do not take part in any of the series given in this paper, but are combination lines, associated by the fact that their wave-number difference is equal to 1P − 2P. They would form, for instance, the first two members of a series $91545 - m$P. The third member of such a series ($\lambda = 1223$) would lie outside the present boundary of investigation in the ultra-violet. The limit of the series, however, does not appear to be derivable from the terms of existing series.

‡ See footnote (†) on p. 174.


24
25
26
27
28
29
30
31
32
33
34
35
40
45
50
55
60
70
Quadruplets
Principal
Diffuse
Sharp
m=3
m=3
m=3
m=4
m=2
m=2
m=2
m=2
m=1
m=2
m=2
m=1
m=1
m=2
m=2
m=2
Singlets
Principal
Sharp
$_1\Pi_1$-mP
$_2$P-mΠ_1
m=2
m=1
m=3
m=3


Diffuse Quadruplet
Current Designation
λ = 2535
2654
3023
4344
Diffuse Triplet, $2p_{1,2,3} - 4d'', d', d$
Combination Triplet, $2p_{1,2,3} - 4D$
abc
a = Combination, 2P − 4d′
b = do. , 2P − 4d″
c = Diffuse Singlet, 2P − 4D
λ = 2805
1 2 3
Combline
1,2,3 = Satellites
25
26
27
$1\Pi_2 - m\Delta$
$1\Pi_2 - m\Sigma$

Combination Lines.

λ and intensity.	ν.	ν (calc.)	Formula.	Current designation.
17071·54 (2)	5856·2	5856·1	$2\Pi_2 - 3\Delta'''$	$3p_1 - 4D$
3680·01 (5)	27166·1	27164·8	$1\Pi_2 - 2\Pi_2$	$2p_1 - 3p_1$
3050·46 (1*n*)*	32772·5	32780·5	$1\Pi_2 - 3\Pi_2$	$2p_1 - 4p_1$
3085·29 (1*n*)	32402·5	32403·7	$1\Pi_2 - 3\Pi_4$	$2p_1 - 4p_3$
3144·48 (2*r*)	31792·6	31795·4	$1\Pi_3 - 2\Pi_2$	$2p_1 - 3p_1$
2672·67 (1*n*)*	37404·8	37411·1	$1\Pi_3 - 3\Pi_2$	$2p_2 - 4p_1$
3305·09 (1*r*)	30247·7	30249·8	$1\Pi_3 - 2\Pi_3$	$2p_2 - 3p_2$
3135·76 (2*n*)*	31881·0	31871·6	$1\Pi_4 - 2\Pi_4$	$2p_3 - 3p_3$
36258 (2)	2757·3	2753·4	$2\Pi_2 - 2\Sigma$	$3p_1 - 3{\cdot}5s$
23263 (3)	4297·6	4299·0	$2\Pi_3 - 2\Sigma$	$3p_2 - 3{\cdot}5s$
22489 (3)	4445·4	4444·5	$2\Pi_4 - 2\Sigma$	$3p_3 - 3{\cdot}5s$

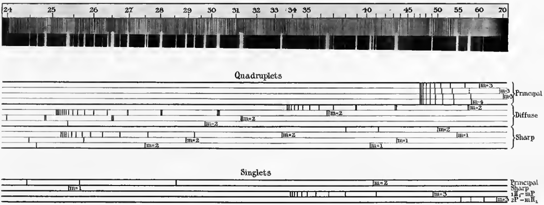
* These lines are given as combinations by Paschen ('Ann. d. Phys.,' vol. 35). The somewhat large differences between observed and calculated wave-numbers cast some doubt on the identification.

Description of Plates 4 *and* 5.

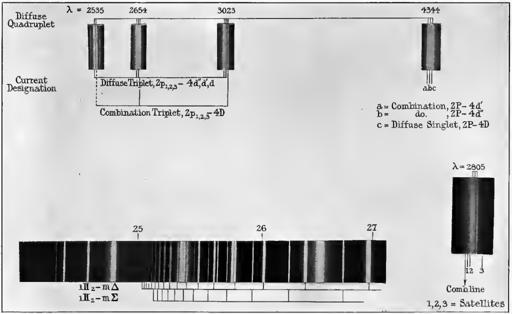
4. In the analysis of the spectrum, each series formed of corresponding components of a quadruplet series is given a separate row. The value of *m* is indicated for the first line in each row. A complete quadruplet is composed of four components, having the same value of *m*, one taken from each row of the space allotted to the series to which it belongs. In the diffuse series, the four components contain, respectively, 3, 4, 3, 2 lines, but they are not, in most cases, completely resolved in the reproduction. (In printing, the wave-length scale has been displaced very slightly to the right.)

5. This plate shows separate portions of the spectrum appearing in Plate 4, as described in the paper. The distances between the components of the second diffuse quadruplet are not on the same scale as the intervals between the lines forming each component. The component of the third diffuse quadruplet, with satellites, which is shown separately, is on a larger scale than the other photographs on the plate.

In conclusion, I wish to express my thanks to Prof. A. Fowler, F.R.S., for constant advice and help, both direct and indirect, in the work leading up to this paper, and to Mr. F. S. Phillips, B.Sc., for permission to reproduce the photograph used in the plates.



4. In the analysis of the spectrum, each series formed of corresponding components of a quadruplet series is given a separate row. The value of *m* is indicated for the first line in each row. A complete quadruplet is composed of four components, having the same value of *m*, one taken from each row of the space allotted to the series to which it belongs. In the diffuse series, the four components contain, respectively, 3, 4, 3, 2 lines, but they are not, in most cases, completely resolved in the reproduction. (In printing, the wave-length scale has been displaced very slightly to the right.)



5. This plate shows separate portions of the spectrum appearing in Plate 4, as described in the paper. The distances between the components of the second diffuse quadruplet are not on the same scale as the intervals between the lines forming each component. The component of the third diffuse quadruplet, with satellites, which is shown separately, is on a larger scale than the other photographs on the plate.